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IN THE EARTH'S ATMOSPHERE

- USSR -

by V. P. Dokuchayev

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FOREWORD

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ELECTRICAL DISCHARGE DURING THE FLIGHT OF METEORS
IN THE EARTH'S ATMOSPHERE

+ USSR -

Following is the translation of a Russian article by V. P. Dokuchayev appearing in the Doklady Akademii Nauk SSSR (Reports of the Academy of Sciences USSR), Moscow 1960, vol. 131, No. 1, pp 78-81.⁷

As is known, the flight of meteors through the earth's atmosphere is accompanied by various electromagnetic phenomena¹. Besides intense optical radiation, there is observed a characteristic radio emission from the ionized meteor trails in the long and medium wave lengths^{2,3}. During the flight of bright bolides and meteors deviations of a compass needle have been noted. In several photographs of large meteors one can observe a luminous aureole around a flying particle. In the zone of the polar aurora the passage of a meteor leads to an "ignition" of visible light. It is possible that ordinary meteors participate in forming the micropulsations of the magnetic field of the earth⁴.

The calculated experimental facts can be explained by the electrical charge in a gas, caused by the flight of meteors through the upper layers of the atmosphere of the earth.

However for this to occur a mechanism is required that will explain the appearance of sufficiently strong electric fields, having a field strength E larger than the breakdown voltage E_b .

A. I. Lebedinskiy^{5,6} has considered the charge of the ions here as applied to the gas charge, and Wulf⁷ has considered it as applied to the particular radiation of the night sky. In these works it was considered that the gas charge occurs in induced electric fields. A strong induced field arises in the zone of the polar aurora as a result of the motion of fast particles of solar origin across the lines of force of the geomagnetic field. Wulf was interested in altitudes of about 200 km where the breakdown voltage is not large. In the meteor region of altitudes of 80-120 km the homogeneous electrical fields do not exceed the breakdown voltage. The earth's electrical field quickly falls off in a direction above the earth's surface and is no greater than 10^{-7} v/cm at the altitudes mentioned. The induced electric field E_i is formed in this region on account of

the solar wind, and it is given by the formula^{8,9}

$$E_1 = \frac{1}{c} [VH_0], \quad (1)$$

where V is the velocity of the medium and H_0 is the magnetic field of the earth. Assuming that $V = 100$ m/sec and $H_0 = 0.3$ gauss, we get $E = 3 \cdot 10^{-5}$ v/cm. It is shown in an article⁸ that as a result of the polarization of the E-layer of the ionosphere there is formed an electric field of strength $E_p = \frac{c}{4\pi} E_1 = 10^{-4}$ v/cm, where σ and σ_H are the transverse and Hall electrical conductivities. Thus, in the meteor region there are induced electric fields of strength $E_0 = 10^{-5}$ v/cm.

The passage of a meteor through the upper layers of the atmosphere is accompanied by the observation of a strongly ionized trail, consisting mainly of electrons and ions of the material of the meteor (meteoric plasma). The concentration of electrons in the trail is several orders of magnitude greater than the concentration of electrons in the ionospheric plasma surrounding it. Thus, for a meteor of 4.5 stellar magnitude the concentration at the initial time is $N_0 \approx 10^9$ electrons/cm³, while even at the maximum of the E layer at a height of 110 km, $N_m \leq 2.5 \cdot 10^5$ electrons/cm³.

As a result of this, we can assume that a meteoric particle leaves behind itself a cloud of highly conducting gas surrounded by a gas of significantly lower conductivity. It is essential that this cloud have the form of a strongly elongated continuous cylinder with a mean length of $l = 10$ km and a radius $R = 5$ m. On the other hand, it is known that every conductor in the external electric field E_0 is polarized and distorts the geometry of this field in such a way that near the sharp corners of a conducting body an increased inhomogeneous electric field appears. This comes about as a result of the polarized charges on the surface of a conductor.

In order to determine the effect of the increase of electric field near the edges of the meteor trail, we approximate it by a strongly elongated ellipsoid of revolution; to this end electrostatics is used to calculate the field from a charged filament of finite dimensions¹⁰. In the case where the external electric field E_0 is oriented along the major axis of the conducting ellipsoid of revolution (the axis of the trail), it is easy to find the strengthened field near its vertices¹⁰:

$$E_{\max} = \left(\frac{1}{r_t} \right)^2 \frac{E_0}{\lg(2l/r_t) - 1}, \quad (2)$$

where $r_t^2 = 4Dt / r_0^2$ is the effective radius of the trail (the minor semiaxis of the ellipsoid); D is the diffusion coefficient and r_0 is the initial radius of the trail.

It is obvious that the increase of the field E_0 , in which the moving meteor forms its ionized trail, will be greater in the leading part of the trail, since the radius of the initial portion increases over the time of flight as a result of diffusion, and the field decreases in accordance with formula (2). We introduce as average values $r_t = 5$ m and $l = 10$ km, then the increased field in the leading part of the trail will be $E_{\max} = 10^6 E_0 = 10$ v/cm. The field is increased along the entire length of the ellipsoid, but the greatest increase occurs near the vertex at a distance of about $d = 0.1l$. As a result the strongly elongated, needle-shaped form of the trail leads to an increase in the electric field surrounding the trail by a factor of 10^6 . The degree of increase depends on the angle at which the meteor flies with respect to the lines of force of the electric field E_0 : for a transverse passage there is practically no increase. It is easy to show that the surface strength $E^2/4\pi$ acting in the direction of the increased field on the surface polarized charges does not exceed the partial pressure of the meteor plasma and has no particular mechanical effect on trails with an electron density $N_0 \leq 10^{10}$ electrons/cm³.

The value of the breakdown voltage of the electric field, leading to the appearance of an electric gas charge, can be found by using the well known expression¹²

$$E_b = \frac{Ap}{B \sqrt{\log(pd)}} \quad (3)$$

where p is the gas pressure in millimeters of mercury; d is the length of the discharge gap in centimeters; and $A = 2.6 \cdot 10^3$ and $B = 0.68$ are constants connected with the ionization coefficients of the electrons and ions¹¹. At the average height of the meteor region $h = 92.5$ km, we introduce $p = 10^{-3}$ mm of mercury¹³ and $d = 1$ km is the mean diameter of the region of the increased field. Substituting these values in formula (3), we get $E_b' = 1$ v/cm. Perpendicular to the magnetic field of the earth the breakdown voltage increases to:

$$E_{np}'' = \frac{\sigma_0}{\sigma_1} E_{np}', \quad (4)$$

where σ_0 and σ_1 are the electrical conductivities along and across the geomagnetic field⁹ respectively. At a height $h = 110$ km, $E_b'' = 10$ v/cm. A comparison of the breakdown voltages and the increased field at the leading part of a meteor trail shows that it is possible to fulfill the breakdown conditions¹¹. Thus the increase of the electric field near the moving meteor leads to the formation of one kind of gas charge.

On the basis of this one can draw the conclusion that the luminous aureole near the moving meteor arises as a result of corona formation in the leading part of the ionized trail. The corona occupies the entire region of the inhomogeneous electric field and has a diameter of the order of 1-2 km. The passage of bright meteors

in strong electric fields can be accompanied by a changeover from a coronal discharge to a spark type of lightning. The development of a path for a spark discharge is facilitated by the presence of the conducting cylindrical trail, the leading part of which spreads with a velocity of about 5-10 km/sec¹¹ leading to an increase in the true velocity observed by means of radio-locating stations. Radio emission both of the corona and the spark discharge lead to interference in radio reception in the long-wave region.

In a spark discharge the electric current along the trail increases significantly, and this can lead to micro-oscillations in the magnetic field of the earth. We shall introduce approximate values for the current in the case of electric breakdown. We shall assume that the trail breaks down under the action of the processes of diffusion and recombination. In this case the concentration of the meteor plasma is determined by the formula¹⁴

$$N(r, t) = \frac{Q}{r^2_t(1 + kQt)} e^{-r^2/r^2_t}, \quad (5)$$

where Q is the initial linear density of electrons, and k is a recombination coefficient. The current density in the absence of breakdown $j_0 = \xi E_0$, where the conductivity $\xi = \sigma N(r, t)$. The total current I_0 through a cross-section of the trail can easily be found by integrating j_0 over this cross-section:

$$I_0 = \int_0^\infty \int_0^{2\pi} r j_0(r, t) dr d\varphi = \frac{\sigma Q E_0}{1 + kQt} \quad (6)$$

In accordance with the general theory of electric discharge, the spatial distribution of the increased current can be evaluated from the formula $I \sim I_0 e^{-\alpha d'}$, where α is the ionization coefficient of an electron and d' is the effective discharge gap. Taking into account the inhomogeneity of the electric field and the space charge connected with it, the exponent in the exponential $\alpha d' = 8$. As a result the current is increased by a factor of 3000. For $\sigma = 100 \text{ cm}^3/\text{sec}$, $Q = 10^{13} \text{ electrons/cm}$, and $E_0 = 10^{-5} \text{ v/cm}$, the initial current $I_0 = 10^{-2} \text{ amp}$, while the increased one reaches a value $I \sim 30 \text{ amp}$. Such a current could cause a microvariation in the magnetic field of the earth $\Delta H_0 = 10^{-7} \text{ gauss}$.

The indicated calculations are correct for meteors passing through the electric field near the surface of the earth, which in fair weather has the average value $E_0 = 1 \text{ v/cm}$. An increase of the field by a factor of 10^4 in the leading part of the ionized meteor cloud may also exceed the breakdown voltage in the troposphere $E_b = 3 \cdot 10^4 \text{ v/cm}$. St. Elmo's fire and electric discharges in the form of lightning, occurring in the fall of meteors have been noted by several observers¹.

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